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TECHNICAL MEMORANDUM

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TITLE: PRELIMINARY EXAMINATION OF PROTOTYPE REFRACTORY BIMETALLIC TUBING FROM NUCLEAR METALS, INCORPORATED

ABSTRACT

Prototype tubing of Cb/316SS and Cb-1Zr/316SS from Nuclear Metals, Incorporated were evaluated to determine the bond quality. The tests employed were metallographic and ultrasonic inspection before and after coiling to an eight-inch diameter. This tubing was produced by hot co-extrusion and cold reduction. The bond in the Cb/316SS tubing was perfect on the basis of the tests applied. The Cb-1Zr/316SS tubing had extensive unbonded areas in the as-received condition. After coiling, the entire outside diameter of this coil was unbonded.

APPROVED:

DEPARTMENT HEAD R. S. Carey

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NOTE: This document is considered preliminary and is subject to revision as analysis progresses and additional data are acquired. The general reader may encounter internal reference not available to him.

AEROJET-GENERAL CORPORATION

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I. INTRODUCTION

In November 1962, Aerojet-General placed a purchase order with Nuclear Metals, Incorporated for 500 feet of bimetallic tubing (316 stainless steel cladding on a columbium - 1% zirconium liner). An initial production run of 150 feet was scrapped by the vendor because it was grossly unbonded and the Cb-1Zr liner was split in many areas. A small tube length was furnished for laboratory work and tube joining studies. This tube section contained extensive unbonded areas.

Nuclear Metals embarked upon an in-house investigation to determine the cause of the manufacturing difficulties. The conclusions were:

1. Sound, tube blanks were produced using their normal hot extrusion practice.
2. Transverse cracks developed at the interface diffusion zone in the Cb-1Zr when cold reducing the tube blank.
3. Small reductions, under 10%, and intermediate anneals did not eliminate crack formation.

This investigation was concluded by producing a short tube length under each of the following conditions:

1. Hot extrude Cb-1Zr/316SS direct to size, thus eliminating the detrimental cracking attributed to tube drawing.
2. Fabricate tubing of unalloyed columbium/316 stainless steel using hot-extrusion and cold-drawing.

Nuclear Metals produced and delivered three prototype tube lengths. The material of one was unalloyed columbium clad with 316 stainless steel; the other two were Cb-1Zr clad with 316 stainless steel. The tubes were evaluated to determine the bond quality.

II. PROCEDURE

A section was taken from the end of each tube and metallographic specimens were prepared. These are shown as Figures 1, 2, and 3. The tube lengths

were then subjected to ultrasonic inspection. Autographic recordings of this inspection are shown as Figures 4, 5, and 6. A three-foot length of each tube was coiled, cold, to an eight-inch diameter and three metallographic sections were made from well-separated locations in each tube. Typical photomicrographs are shown as Figure 7. The tube remnants were inspected on the outside diameter of the coil by ultrasound using a manual probe.

III. DISCUSSION

The two tubes containing the Cb-1Zr liner were produced by direct hot co-extrusion with no subsequent cold reduction. The extrusion ratio was about 40:1. To use this ratio, it was necessary to employ an extrusion temperature in excess of 2100°F, in order to reduce the extrusion pressures to the capacity of the press. Prior to this experiment, they had employed an extrusion temperature of 1800°F. Metallographic sections of specimens from the two tubes are shown as Figure 1 for tube #1, and Figure 2 for tube #2. Tube #1 contained gross voids at the interface; tube #2 appears to be sound. Ultrasonic inspection indicates that gross bond defects are present in both tubes and that in the case of tube #2, an isolated sound area had been sampled. After the tubes had been coiled, both metallography and ultrasonic inspection indicated a complete lack of bond in the outer fiber.

The diffusion zone, as seen in Figure 1, is 0.0012 in. The diffusion zone in previous Cb-1Zr/316 tubing produced by hot extrusion and cold reduction was 0.000015 in. The exceptionally wide diffusion zone was produced by a combination of high-extrusion temperature and a slow-extrusion rate. It is judged that the zone fragmented during the last stages of extrusion and the voids seen in Figure 1 resulted from particles being pulled out during metallographic specimen preparation. Nuclear Metals, Incorporated attributes the detrimental results of diffusion to the formation of zirconium carbide.

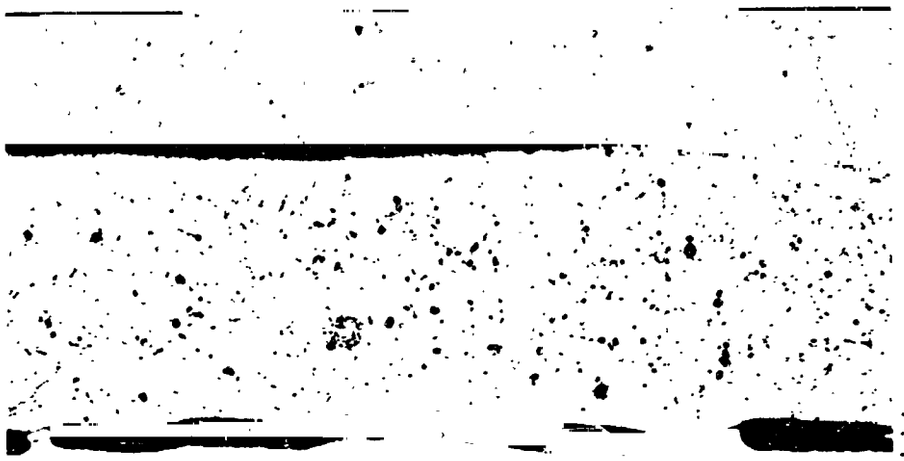
Visually, the quality of the Cb-1Zr/316SS tubing was poor. The surfaces were rough. The wall variation and ovality were high. Metallographic specimens showed wall variation of 20% and ovality of 0.030 in. The liner thickness varied from 0.008 to 0.021 in. These items would increase the difficulty of developing satisfactory joining techniques.

The single tube length having the unalloyed columbium liner was produced by hot co-extrusion at about 1800°F, with an extrusion ratio of about 10:1, and then cold-drawn to size. This tube contained a light score on the I.D. surface. Other than this, no defects were detected. The as-received tubing showed excellent bond by metallography (Figure 3), and by ultrasonic inspection (Figure 6). After coiling to an eight-inch diameter, no deterioration could be detected by either metallography or ultrasound. Photomicrographs of sections after coiling are shown as Figure 7.

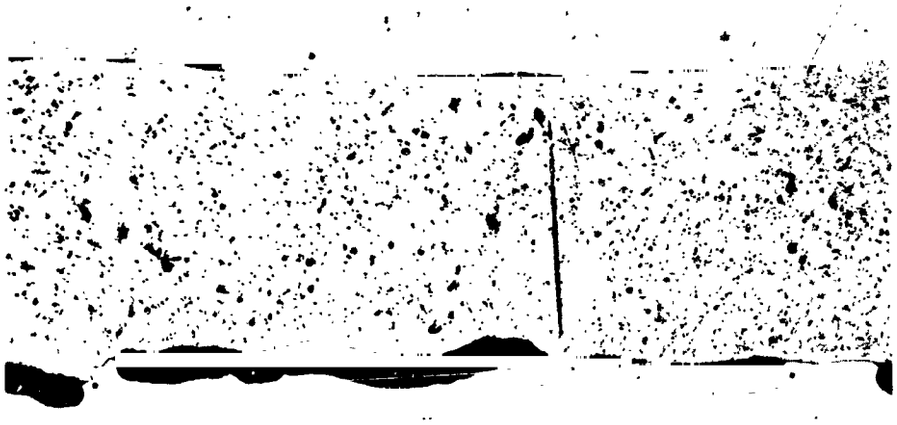
IV. CONCLUSIONS

1. The production of Cb-1Zr/316SS bimetallic tubing, having sound metallurgical bonding, is beyond the existing state-of-the-art.

2. The feasibility of producing unalloyed columbium/316SS bimetallic tubing was demonstrated.



As Polished Longitudinal 100X



As Polished Transverse 100X

Longitudinal and Transverse Photomicrographs of Cb-1Zr/316 SS Tubing
(As Received)

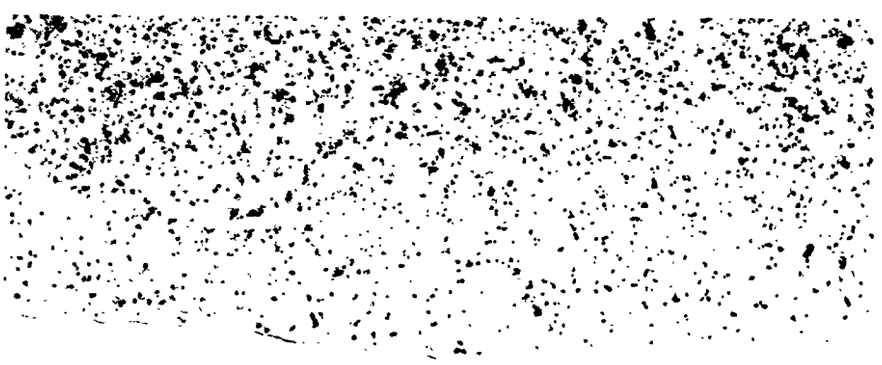
Figure 1

Cb-1Zr

316 SS

As Polished 100X

Longitudinal



Cb-1Zr

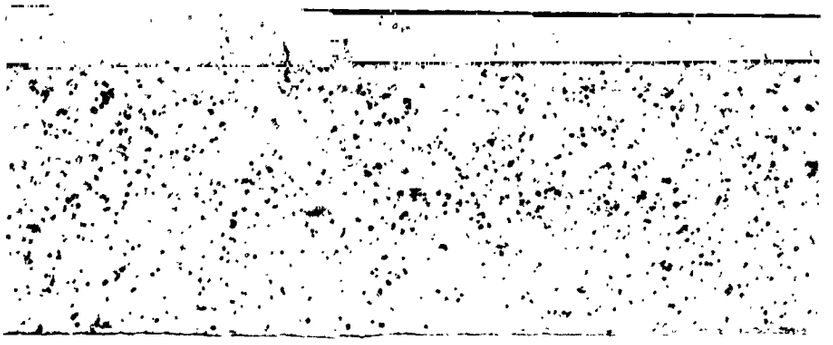
316 SS

As Polished 100X

Transverse

Longitudinal and Transverse Photomicrographs of Cb-1Zr/316SS Tubing
(As Received)

Figure 2

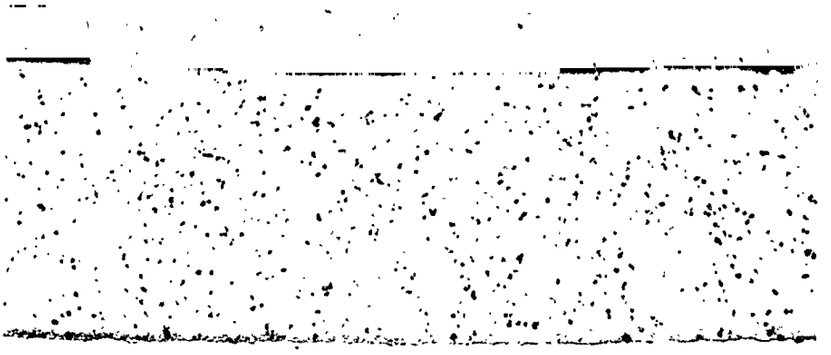


Columbium

316 SS

As Polished 100X

Longitudinal



Columbium

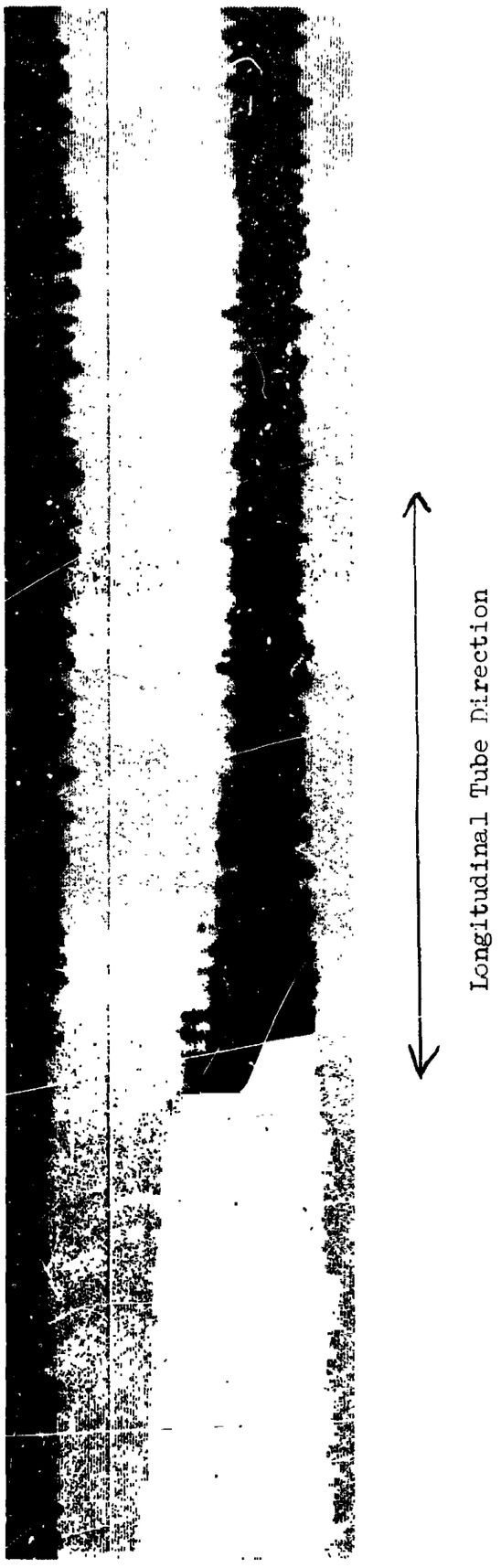
316 SS

As Polished 100X

Transverse

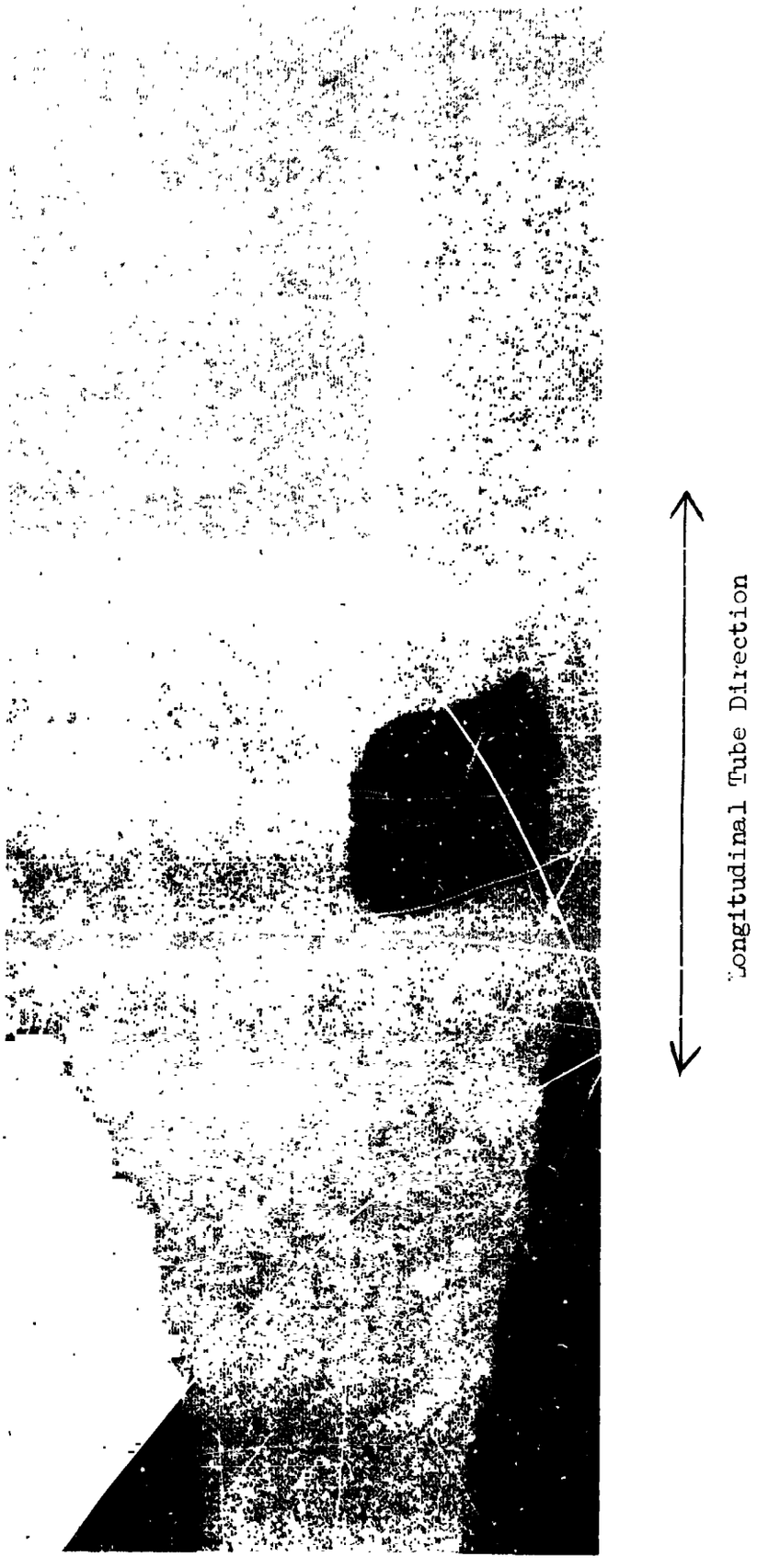
Longitudinal and Transverse Photomicrographs of Cb/316SS Tubing
(As Received)

Figure 3



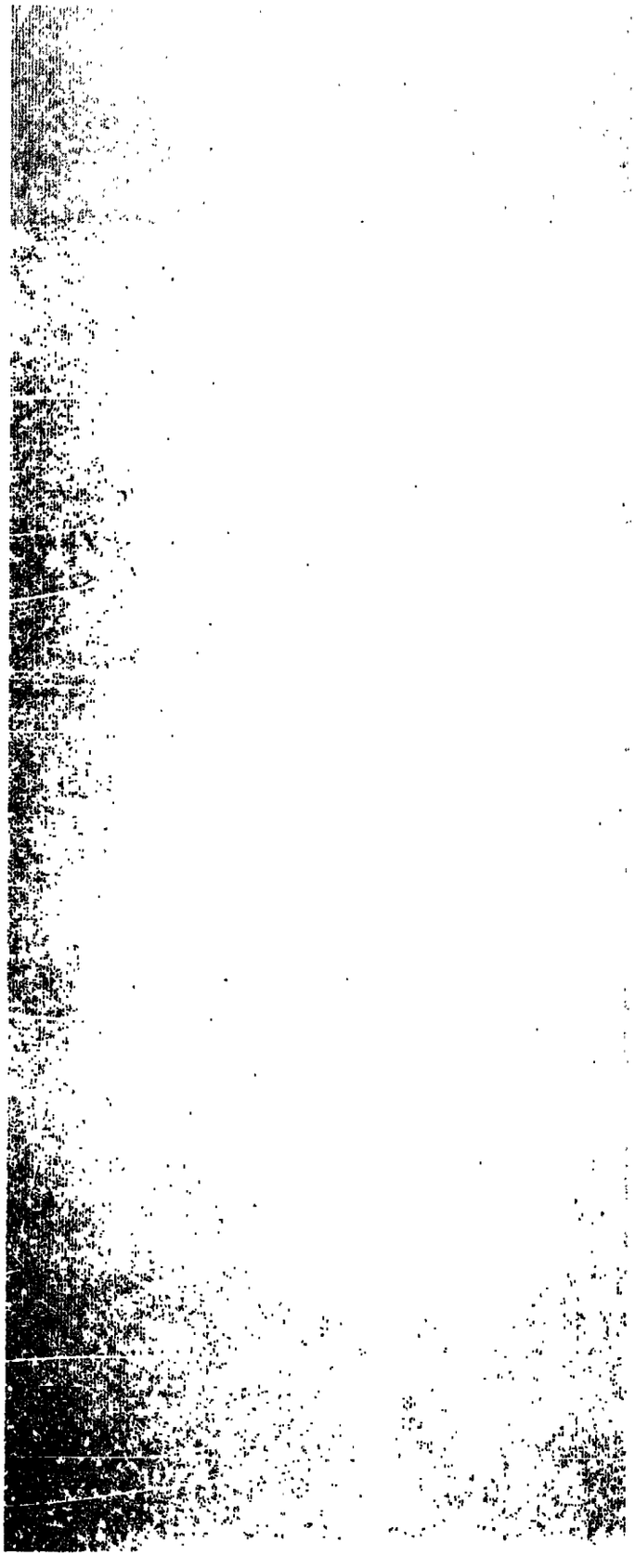
Typical Autographic Recording of Ultrasonic Inspection Results on Cb-1Zr/316 SS Tubing,
(NOTE: Dark Areas Show Bond Defects)

Figure 4



Typical Autographic Recording of Ultrasonic-Inspection Results on Cb-1Zr/316 SS Tubing,
(NOTE: Dark Areas Indicate Bond Defects)

Figure 5



Typical Autographic Recording of Ultrasonic Inspection Results, Columbium-
316 SS Tubing, As-Received (Note: Dark Areas, If They Had Appeared, Would Indicate Defects)

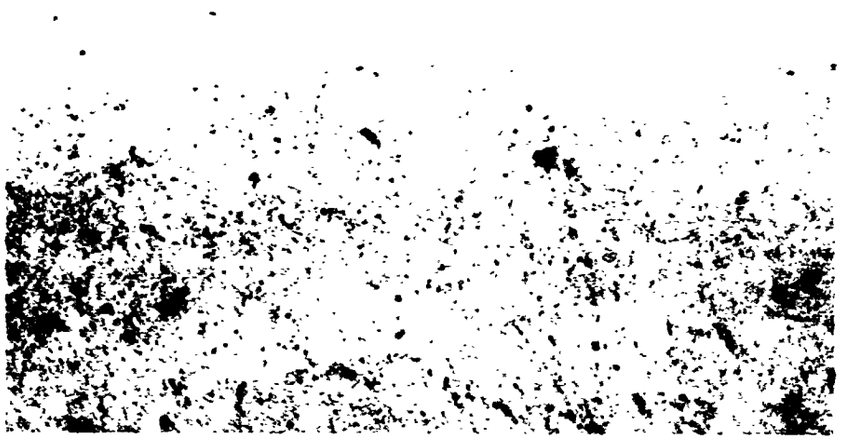
Figure 6

Columbium

316 SS

As Polished 1000X

Columbium



316 SS

As Polished 1000X

Bond Area of Unalloyed Cb/316 SS Tubing After Coiling to an 8-Inch Diameter (Transverse)

Figure 7